National Aeronautics and Space Administration

Extravehicular Activity (EVA) and Planetary Protection

Study Area 2: Addressing technology and operations for contamination control

Planetary Protection Workshop
NASA AMES
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JSC-XX/EVA Management Office
March 26, 2015

Agenda

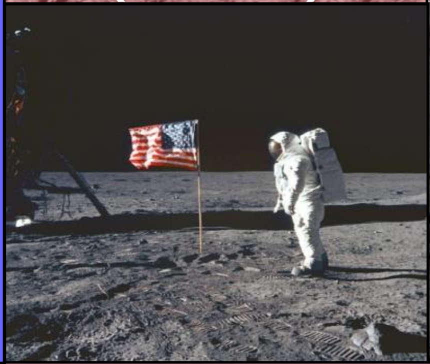
- A *Brief* History of EVA
- Progress in Exploration EVA
- Current Efforts and Next Steps
  - "Plausible Protection" Criteria
  - Layered Approaches
  - Vehicle Architectural Implications
- Planetary Protection's Detailed Questions
- Suggested Future Testing, Demonstrations and Coordination
- Conclusions
- Backup Slides

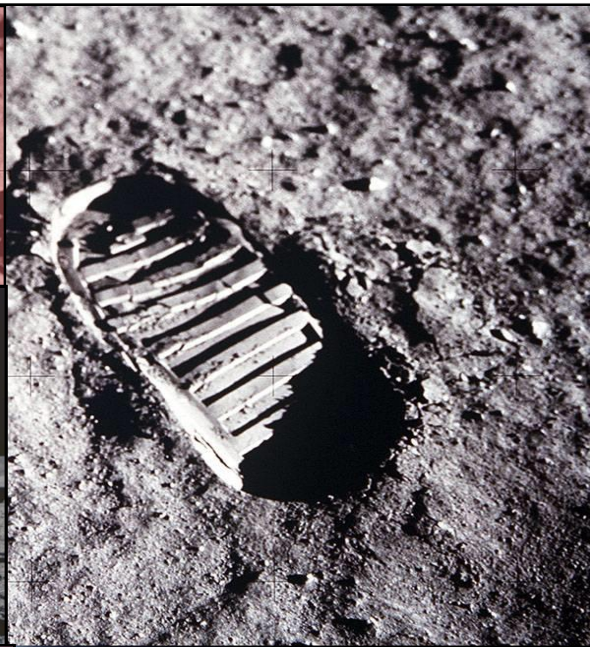
A *Brief* History of EVA

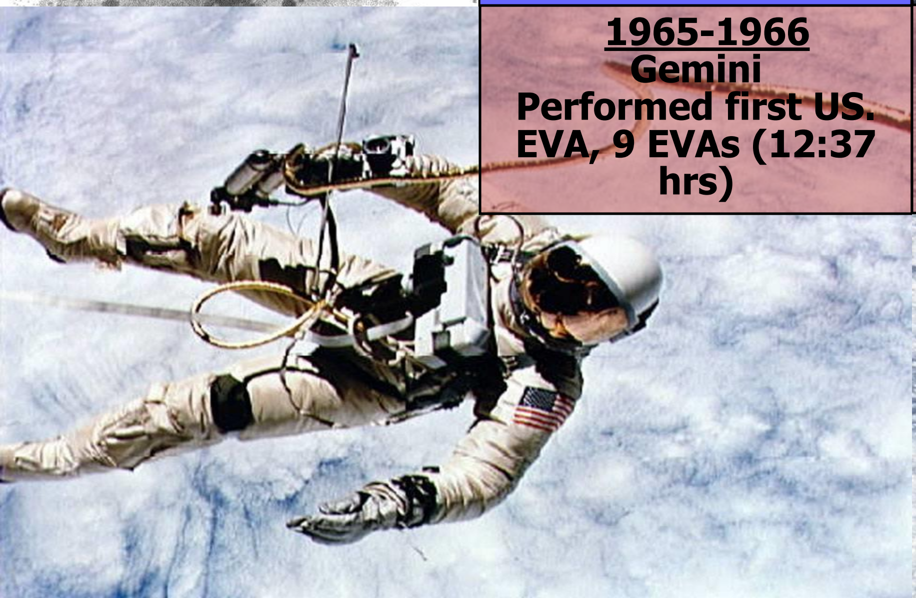
Pressure Suits and EVA Through the Early Years

(Circa 1940)
Subject: Wiley Post Outfitted in early version of high altitude pressure suit, manufactured by B. F. Goodrich.

1969 – 1972
Apollo
Six lunar landings, 19 EVAs (84:31 hrs)

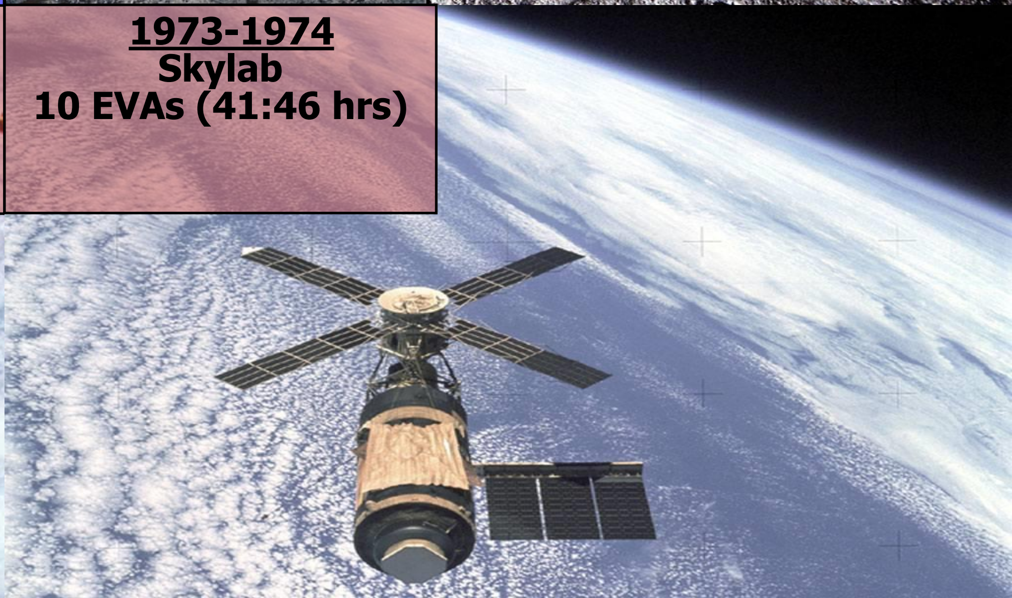




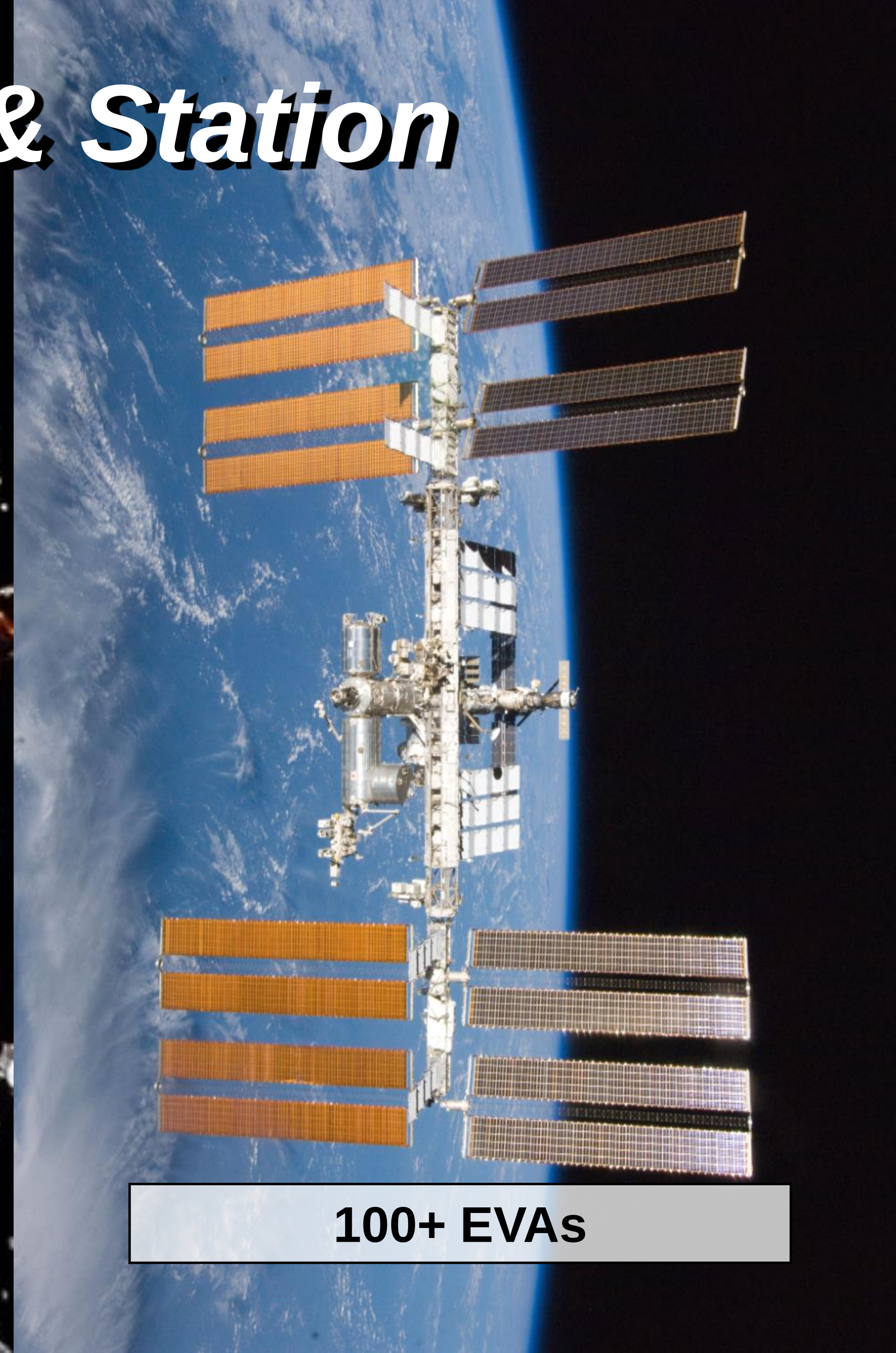


1965-1966
Gemini
Performed first US. EVA, 9 EVAs (12:37 hrs)

1973-1974
Skylab
10 EVAs (41:46 hrs)



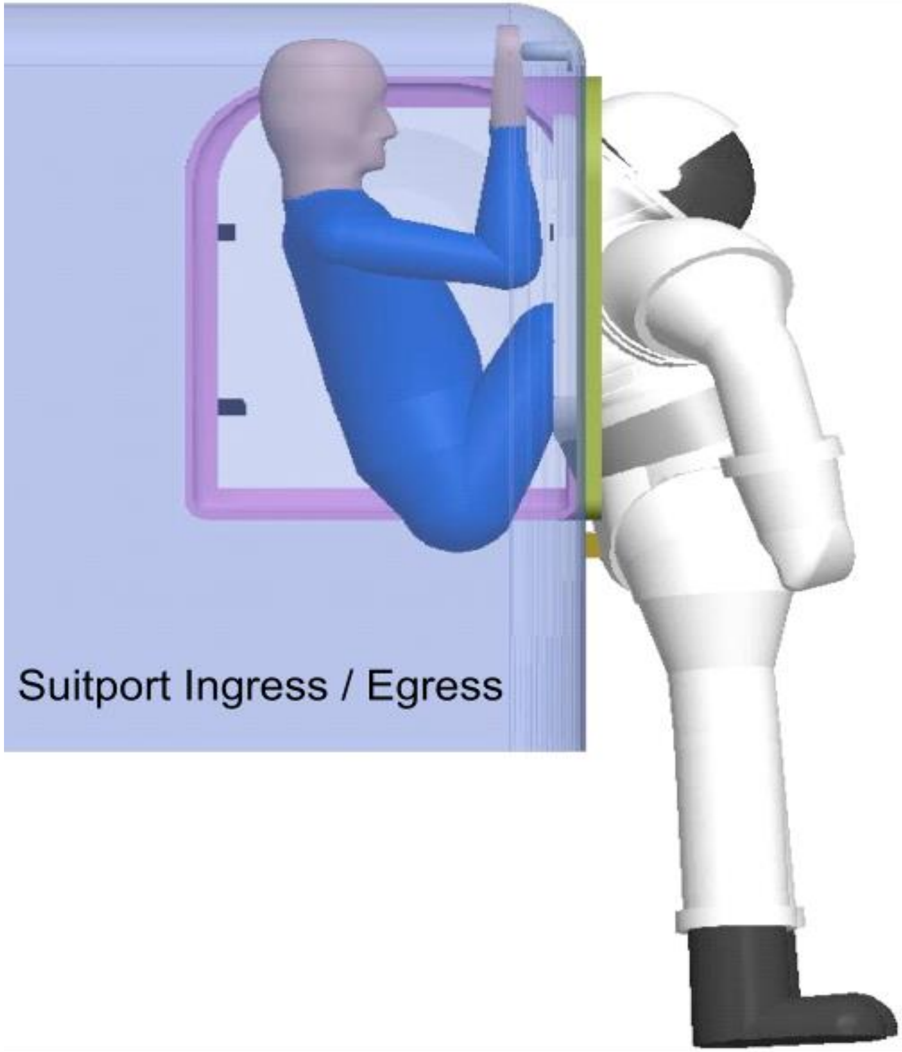
Shuttle & Station



Progress in Exploration EVA

- **Since the ~2005 Houston Life Support, Habitation and Planetary Protection Workshop, there technical progress in at least two EVA areas relevant to Planetary Protection has been achieved:**
  - First, 1g demonstration of pressurized rear-entry suit donning has been conducted
    - This first look at delta-P donning provided insight into additional features and challenges to be addressed
  - Second, the EVA Community has shifted towards a “two suit” architecture following occupant injury testing in CxP
    - This means that a separate Launch-Entry-Abort suit would be used, allowing EVA suits to be dedicated to EVA (different from Apollo)
    - Practically, this has led to an opportunity to discuss leaving EVA suits on a planetary surface, aiding in Planetary Protection efforts by “leaving the contaminated suits behind”

- **What improvements do rear-entry suits offer for Planetary Protection concerns?**
  - If donned via a bulkhead, the structural plane provides a significant barrier for much of the suit-born contamination (dust)
  - This reduces the amount of casual contact between the crew as they don/doff suits



Current efforts and Next Steps

"Plausible Protection" Criteria

- **Borrowing from Dr. Eppler: The definition of Planetary Protection needs in relation to how it impacts EVA mission & system element development costs should be considered and interpreted as follows:**
  - Since EVA operations will have the most direct (wide spread) physical interaction with the Martian surface on a daily/weekly routine basis, "PP" needs should be considered in the following terms to mitigate hardware & operations costs:

"Plausible Protection" Criteria

1. **Identify, quantify and catalog all potential EVA system contamination sources**
2. **Implement reasonable preventative measures (by combination of design and procedures) to reduce contamination sources that would be technically feasible and non-cost prohibitive**
3. **Screen and manage the contamination stream**
4. **Eliminate any unknown constituents – (Given the intimate human interactions with suit systems and atmosphere, and the complexity and variability of the source of contaminants, this may not be practical at a level that will protect science objectives; it is not an unreasonable suggestion that dominant contaminants in an Earth life signature may be a top priority signature to weed out in a search for Mars life)**

What might "reasonable protective measures" look like for EVA and surface assets?

1st Layer – Mission Architecture Design

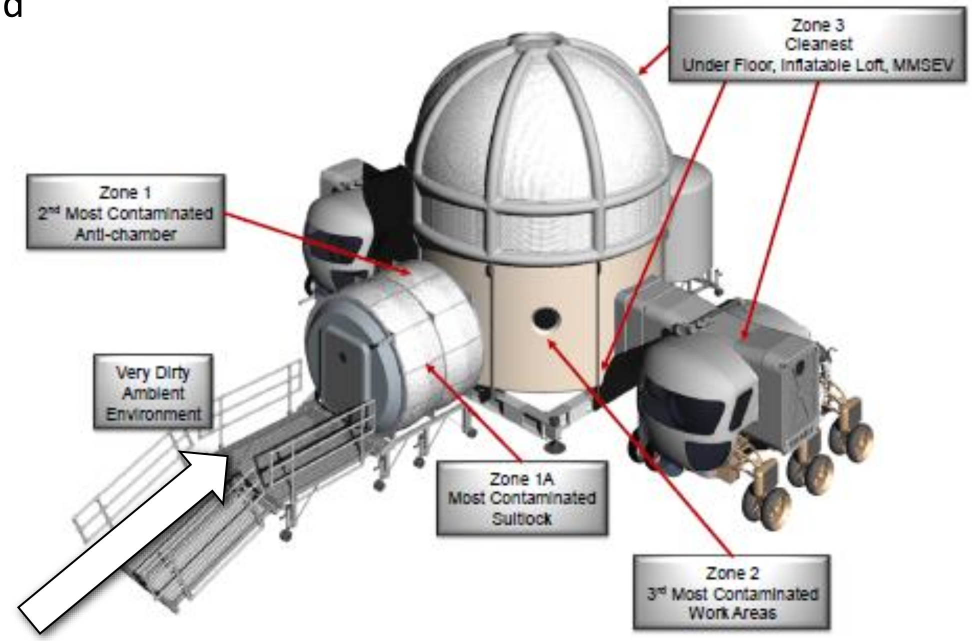
- Avoidance of Special Regions (defined within X radius of lander/habitat prior to the mission)

2nd Layer – Hardware Design

- EVA Suits will leak/vent – Engineering limits must be understood and intentionally accounted for
- Sample tool collection/containment

3rd Layer – Operational Design

- Suit ingress *directly* to habitable volumes should eliminated to extent possible, examples of this include the "Next Generation Airlock" concept (rear-entry suit don/doff through bulkhead)
- Sampling Protocols limit inadvertent contamination
- Leaving EVA suits on surface

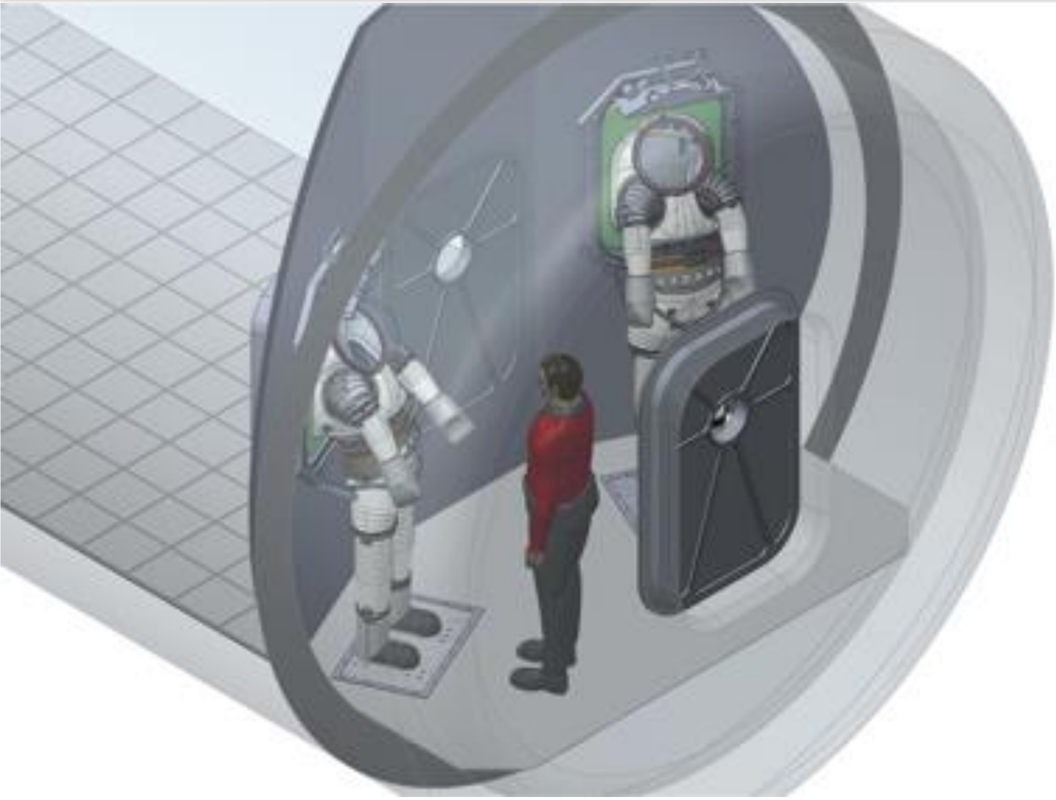


4th Layer – Contamination Control

- Conduct Verifiable Decontamination of EVA Hardware on a regular interval
- Conduct Exterior and Interior Cleaning
- Utilize Air Quality Contamination Zones

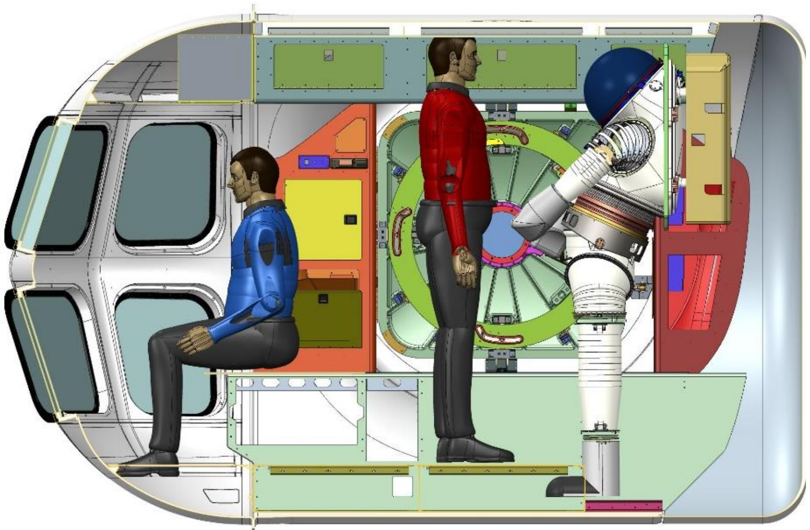
Note: This is an example of a layered defense plan – other protocols can be followed

Current Efforts and Next Steps
Vehicle Architecture Implications



Concept – Next Generation Airlock

- **However, there is usually "more than one way" to solve any issue**
  - From an Architecture perspective, we need to understand volumes and outfitting further, among many things
  - These will be driven in no small part by Planetary Protection
  - Many of the key issues lie not in nominal ops, but in the *contingencies*

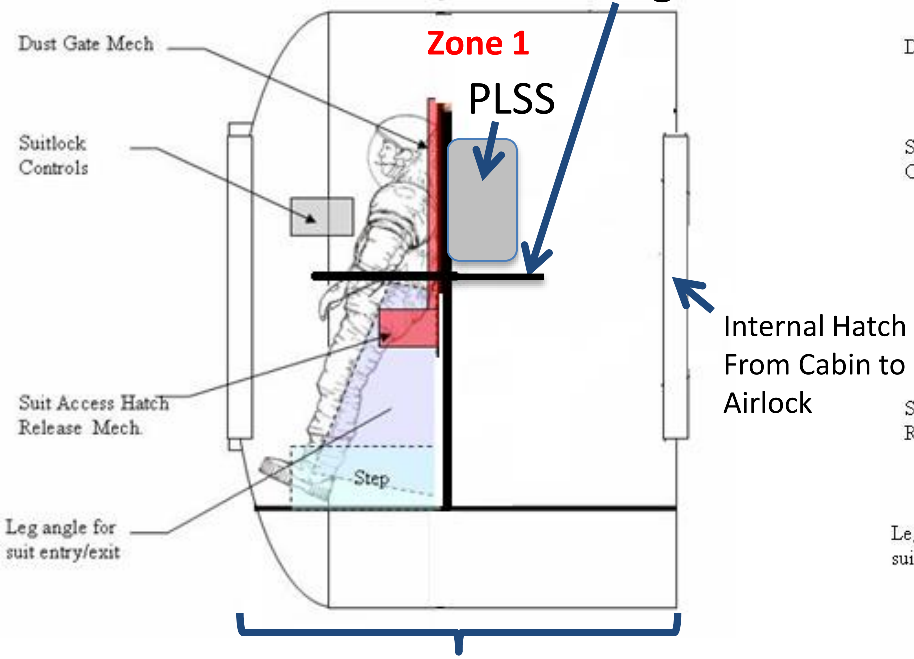


Concept -Habitable Airlock

- **For Instance, what is an acceptable exposure to surface dust during EVA System maintenance events?**

Current Efforts and Next Steps
Operational Design and Contamination Control

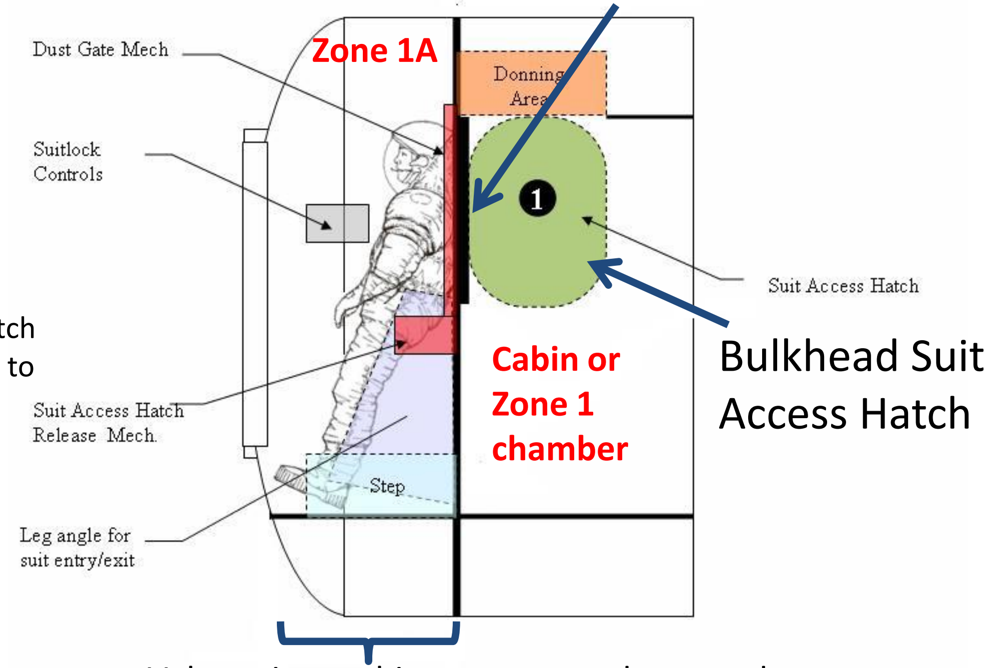
Airlock: with Donning Stand



Volume is at cabin pressure or depressed to vacuum

- Crew dons/doffs with donning stand
- Full airlock volume depressed
- Crewmembers walk through dust prior to and after every EVA

Next Generation Airlock



Volume is at cabin pressure or depressed to vacuum

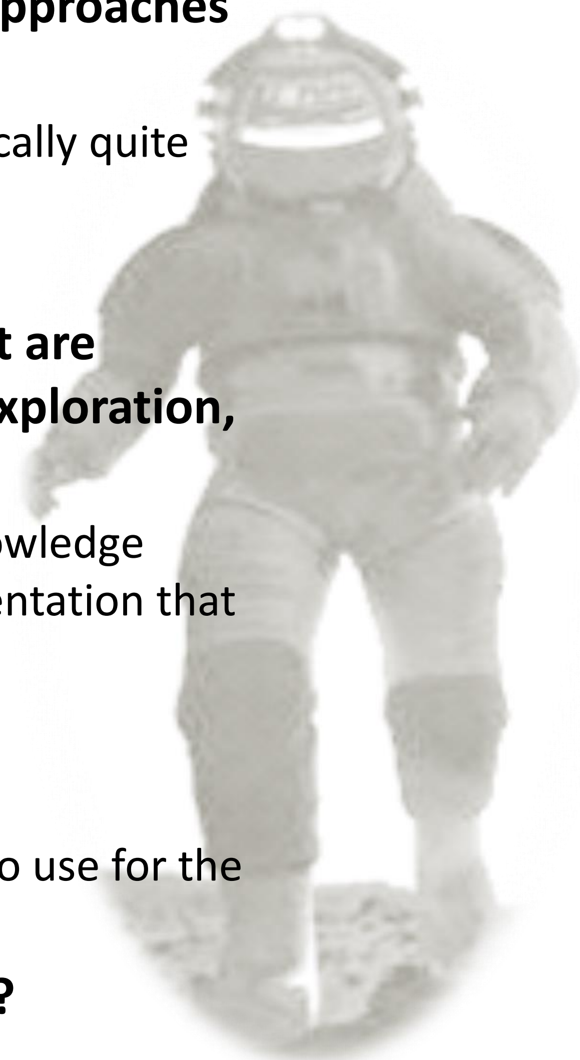
- Crew dons/doffs through Bulkhead
- Egress occurs once Rear-Entry Airlock is isolated (Bulkhead Suit Access Hatch closed) and volume is depressed
- Minimal airlock volume depressed
- Dust Mitigation is increased by adding Zone 1A barrier and potential Zone 1

Planetary Protection Workshop Questions

- **What planetary protection (PP) related research activities or technical developments do you feel are critical for inclusion in your study area?**
  - EVA needs Suit materials testing to understand chemical interaction
  - Cleaning tools design and procedural use definition is an unknown
  - Ingress/egress method design options need to be weighted from a Planetary Protection perspective
- **What work/research is already underway?**
  - Exploration EVA Suit design is ongoing, with requirements development and potential ISS EMU replacements in discussion
- **Is special information or technology needed to plan for nominal vs. non-nominal situations?**
  - Suit failure/Incapacitated crewmember operations must be pre-planned
  - A thorough dialogue is needed to evaluate how contingency operations would be conducted and still fulfil the intent of Planetary Protection guidelines

Planetary Protection Workshop Questions

- **Are existing human mission mitigation options and approaches adaptable for PP needs on the Martian surface?**
  - Personal Protective Equipment for suit servicing is historically quite limited
  - Air flow control is has also been quite limited in flight
- **Are there any significant stumbling blocks ahead that are evident? (Including coordination across PP, science exploration, engineering, operation and medical communities.)**
  - Coordination across communities must be increased: Knowledge gained from current/future programs on Mars to documentation that can be applied to Exploration EVA development
    - Environments documentation is needed
    - Direction on simulants use for testing
  - Concurrence on testing of ingress/egress methods prior to use for the first time for mission success/planetary protection
- **In your opinion, what still needs to be accomplished?**
  - See Future Testing/Demonstrations and EVA Needs slides



Suggested Future Testing, Demonstrations and Coordination

- **Suit Materials testing on Mars 2020 rover is being pursued**
  - This by itself will likely not answer all questions associated with chemical compatibility
- **Ground Testing and Analogs**
  - Ingress/egress methods with suits on other side of bulkhead (Next Generation Airlock)
  - Coordination on the “best” combination of layered controls and technology concepts is highly desired
    - This should include nominal prevention and cleaning, contamination detection technology, detailed contamination control and removal/cleaning technology?
  - Cleaning/Sterilization must be compatible with the suit material limitations
  - Environment characterization/definition (properties of dust/dirt, dust storms, etc.)
  - Mars simulant (require knowledge, not necessarily Mars sample return)
    - Additives to trace backward contamination?
    - Chemical additives to understand materials degradation due to toxicity/corrosion?
  - Programmatic requirement for testing acceptable levels of dust within the habitable volumes

Suggested Future Testing, Demonstrations and Coordination

- **EVA needs Planetary Protection support for ground and on-orbit testing prior to mission success**
  - Dust mitigation testing should be done prior to Mars surface
  - This can be done at Cis-lunar proving grounds, Lunar Surface (IP missions), and Mars Moons
- **Further evaluation of the Layered Engineering Defense Plan for Dust Mitigation is desired**
  - Operational Design and Contamination Prevention
    - Need support for testing ingress/egress methods prior to use for the first time on Mars surface for planetary protection and mission success
    - Need special region locations for landing site selection
  - Exterior and Interior Cleaning and Protection
    - Need the technology identified for detection and contamination control and removal from Planetary Protection community (next level of detail from the COSPAR Planetary Protection Policy) to understand how it interfaces with the suit and testing needs
    - Need requirements for simulant use during testing from Planetary Protection community
  - Air Quality Contamination Zones
    - Need input/support on architecture zoning concepts

Forward Collaboration

How can we continue the conversation?

- For our breakout session this week, the backup slides to this presentation provide several numerous questions for additional discussion
- Long term, the EVA Management Office at JSC provides a "Front Door" venue through which all stakeholders can engage in the development of future EVA capabilities – The EVA Exploration Working Group (EEWG)
- The EEWG meets every-other-week and provides telecon and virtual meeting support information for participants not resident at NASA-JSC
- The EEWG chair serves as the Deputy of NASA's EVA Systems Maturation Team (EVA SMT) and also chairs the EVA International SMT (EVA ISMT)
  - This provides for comprehensive coordination across the EVA Exploration community both "inside" NASA as well as to our International Partners
  - This includes identification of EVA "Knowledge Gaps", their buy-down plans and coordination of buy-down efforts

- **The EEWG invites participation from the Planetary Protection Community**
  - Contact the EEWG Chair, Jesse Buffington, for additional information
    - jesse.a.buffington@nasa.gov
  - You can also visit the EVA Homepage to see the latest:
    - https://portal.nasa.gov/group/eva/office

Backup

1st Layer: Materials and Engineering Design

- **EVA suits leak and vent**
  - No known way to achieve both mobility AND zero leak (minimize to extent possible without overly constraining design or impeding on human performance)
  - Coincidentally, leaks aren't all bad- they help reduce the buildup of trace gas contaminates not otherwise filterable in the suited system
- **Exploration EVA Suit design includes:**
  - Nominal venting – CO2, water vapor, and trace contaminates
  - Leakage through Bearings
  - Bladder underneath suit restraints and TMDG is generally "air tight"
    - Martian contaminates may intrude under the TMDG getting into fibers and bearings
  - Dust tolerant seals/connectors for water, electrical, and high pressure oxygen connectors, abrasion/cut resistant Thermal Micrometeoroid Dust Garment (TMDG), dust tolerant seal covers (PLSS, SIP, umbilical), minimal dirt collection (pockets)
- **Suit interfaces: include ingress/egress interfaces**
  - Next Generation Airlock concepts are one potential solution

3rd and 4th Layers: Operational Design and Contamination Prevention

- **Special Regions defined through traverse radius prior to crew arrival**
- **Lander: Landing Site Selection**
- **Habitats/Pressurized Rovers:**
  - Next Generation Airlock ingress/egress interfaces:
    - Gas is vented overboard during depress, some percentage could be reclaimed with proper ECLSS filtration on the habitat
      - Nominal EVAs and suit maintenance (must bring suit into pressurizable volume)
        - » Mudroom/Cleanliness Zoning?
      - Incapacitated crewmember (may have to be brought inside in suit)
    - Gas is vented overboard in a contingency case of depressing the habitable volume of the pressurized rover
      - Nominal EVAs from suitports on rover (PLSS will be inside cabin)
      - Contingency suit maintenance (EVA crewmember may need to bring suit inside cabin)
      - Incapacitated crewmember (EVA crewmember may need to be brought inside cabin)
- **Mars Ascent Vehicle**
  - GR&A: crew will nominally ingress Mars Ascent Vehicle (MAV) shirtsleeve, leaving the dirty EVA suits behind on the surface
    - Sample transfer needs to be addressed
    - Contingency scenarios need to be addressed

4th Layer: Exterior and Interior Cleaning

- **Exterior Cleaning and Protection: Minimize to the extent possible any dust/dirt brought into a pressurizable area or ingress/egress method without exceeding the limitations of space suit materials**
  - Prior to ingressing next generation A/L (Zone 1A) from EVA:
    - Stomp or scrape boots on grated porch? Sticky pad? (surface only)
    - Inspect suit (visors, gloves, boots, lights, cameras, TMDG, etc.)
    - Wipe static pressure seals at disconnects on suitports (probably only the seal at the suit port interface plate most of the time based on the current ops con) without depositing or rubbing particles into the seal
    - Wipe down suit and helmet, clean TMDG to extent possible (disposable outer garment?, active cleaning technologies are not currently part of baseline, what other cleaning technologies on exterior?)
    - Crewmembers clean each other's SIP (remove layer of removable dust protection?)
    - How does wipe down/blow off work in microgravity/vacuum and 3/8g/CO2?
- **Interior Cleaning and Protection**
  - Repress (use repress jets to direct repress air towards floor – would this work in mg? Need vacuum system for filtration?), ECLSS filtration in place; Hydrogen peroxide gas, if necessary?, Forced gas shower during repress?, Vacuum cleaner after repress?, Electrodynamic, magnetic tools?, Wipes (wet or dry) for connections?
  - Egress suit through bulkhead to enter cabin Zone 1 (dust curtain or inner chamber barrier between bulkhead and Zone 2?)
  - For Suit Maintenance, crewmember/s don protection booties, TBD protective gear
    - If extensive maintenance/repair needed – take into Habitat maintenance/dust containment area (in Zone 2?, table?, PLSS stand?) or include retractable table inside Zone 1?
    - Include very thorough cleaning of suit inside Zone 1A prior to bringing in Zone 1 or 2 (use protective dust covers)

Why would suits ever be brought inside?

Nominal EVAs for maintenance, crew transfers, etc.

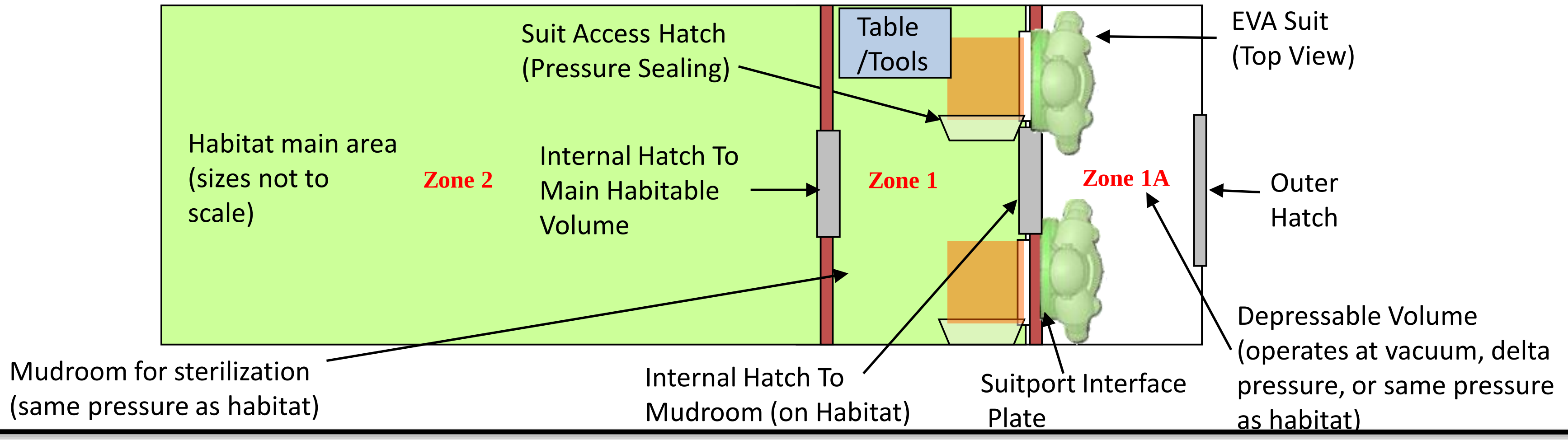
- **Keep in mind: Performing EVAs nominally to/from the habitat pressurizable volume on ~500 day mission likely cannot be done with service access to the suits themselves**
  - Regular suit maintenance (at least every 28 days or TBD EVA hours), more frequent maintenance (glove changeout)?
  - Suit resizing
  - Suit swapping for crew changeout (beginning/end of mission?)
  - Suit swapping for suit end of life (conservatively, about 2-3 per crewmember over the 500 day duration with maximum EVA hours)
  - Other items that need to be maintained or transferred (trash, up front cargo transfer from offloading lander, cargo transfer during mission)
    - SPTM/equipment lock can be used on HAL/PEV
  - Exploration/research near Habitat (science, ISRU, green house?)
  - Other crewmember ingress/egress while SEVs are traversing (Mars surface pioneering)
    - During missions with >4 crewmembers on the surface, some would be left at the habitat while the two rovers go on traverses and would need an ingress/egress method in case of contingency, maintenance, etc.
  - SEV EVAs for exploration, research, landing site surveying, etc.

How would one bring suits inside?
Assuming Layered Controls have been followed…

- **Conducting some amount of suit maintenance in rear-entry A/L (TBD volume) assuming EVA has already been performed to ingress habitat**
- **Suit maintenance can be performed same day or next day, crewmember can remove LCVG and don personal clothing**
  - Inside habitat, retrieve ORUs/spares/tools from habitat for maintenance (minimal/common tool set needed for suit – no specialized tools)
  - Crewmember/s don protection booties, TBD protective gear
  - Rear-entry A/L at slight negative delta pressure to hab during entry/exit?
  - Crewmember ingresses through inner hatch or hatch w/in hatch and performs repair/swapout of component
  - Example: Gloves changeout
    - Clean PPE gloves if necessary, remove glove
    - Use suit side wrist disconnect end cap protection cover or plug to reduce any ambient air dust from getting inside suit
    - Remove end cap cover and glove from bag and replace (compressed air pin point duster)
  - Attach Suit Automated Checkout box (TBD)
  - Remove PPE prior to going into hab (disposable, or reusable?)
    - If surface, place sticky pad on floor to step on for PPE removal
    - Mudroom would be ideal
  - Perform Suit Automated Checkout

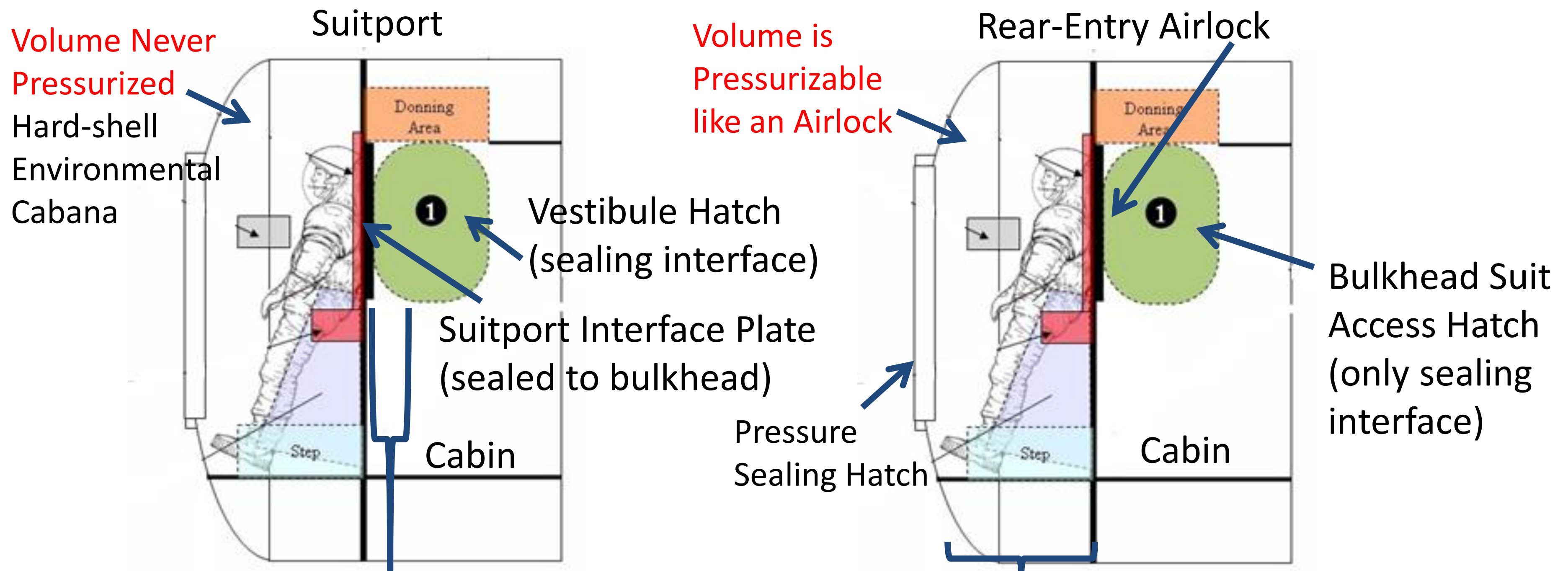
How would one bring suits inside?
Example: 4th Layer "Mudroom" Option (Zone 1 and 1A)

- **Larger pressurizable volume and equipment lock/mudroom behind the bulkhead?**
  - **PRO:**
    - Depressurizable volume large enough to don PPE and work on suits shirtsleeve for suit maintenance and some stowage
    - Suits can be worked on within the 1st contamination control zone (Zone 1A)
    - Equipment lock (Zone 1) behind suitports to aid in contamination control for in-depth suit maintenance
  - **CON:**
    - Extra mass for larger equipment lock/crewlock
    - Larger amount of gas to be reclaimed and lost when used as an airlock



Differences between Suitport and Rear-Entry Airlock

Formerly known as Suitlock



Suitport	Rear-Entry Airlock
Vestibule Volume is at cabin pressure or depressed to vacuum	Volume is at cabin pressure or depressed to vacuum

Suitport

- **Cabin must be at 8.2 psia/34% O2 (near zero prebreathe)**
- **Crew dons/doffs through Bulkhead**
- **Suit must have SIP (pressure seal to cabin)**
- **Suit at 8.2 psid during don/doff**
- **Egress occurs once vestibule volume is depressed**
- **Volume around suits continuously at vacuum**
- **Less Mass**
- **Dust Mitigation is increased**

Rear-Entry Airlock

- **Cabin goes down to 10.2 psia/26% O2 (~40 min. to 3.5 hour prebreathe)**
- **Crew dons/doffs unpressurized suit through Bulkhead**
- **Suit does not need SIP (no pressure seal to cabin)**
- **Egress occurs once Rear-Entry Airlock is isolated (Bulkhead Suit Access Hatch closed) and airlock volume is depressed**
- **Volume around suits is pressurized, minimal airlock volume depressed**
- **More Mass**
- **Dust Mitigation is increased**

Planetary Protection Considerations for Advanced Planetary EVA System Design

- Identify potential contaminants and pathways for Exploration EVA systems with respect to forward and backward contamination
- Identify plausible mitigation alternatives and obstacles for pertinent missions
- Identify topics that require further research and technology development and discuss development strategies with uncertain PP requirements
- Identify PP requirements that impose the greatest mission/development cost
- Identify PP requirements/topics that require further definition

Conclusion: Overall EVA Systems PP Recommendations

- Define specific surface task activities that would require the implementation of appropriate PP measures
- Describe and define the potential physical (chemical or biological) impacts that the identified suit/PLSS vent/leakage constituents would have in regard towards PP "forward" contamination concerns
- Determine what levels of PP back-contamination control are possible or needed for EVA systems; suits, PLSS, airlocks, rovers
- Determine what effect would the natural Martian environment (UV, radiation, thermal, pressure) have towards "natural mitigation" of potential Earth-based contaminants

Planetary Protection Plausible Mitigation Alternatives and Obstacles -

Managing Contamination From Humans in Suits, Backwards and Forwards

- **Minimize surface contact area of initial human-EVA supported activities:**
  - Use robotic precursors (tele-operated or autonomous mode) to scout & survey intended EVA worksite locations and potential science way-point stations prior to human intervention
    - <u>Obstacle</u> – We may be the cost & time overhead associated with robotic vehicle operation; also, there are limitations associated with robotic vehicles as such (lack of real-time decision making, intuition and judgment)
- **Identify “safe” and “no-go” zones adjacent to and within x-radius distance of lander/habitat location for method of control for human-EVA supported traffic**
    - <u>Obstacle</u> – We may not be able to totally exclude “chance encounter” with “oasis-of-life; also potentially restrictive for critical surface operations (location of ISRU plant or power-plant distribution elements)
- **Reduce or eliminate EVA-system element contamination sources**
  - Vent gases, leakages, trace chemical contaminants, material abrasion, etc.
    - <u>Obstacle</u> – This may not totally practical; through normal use and wear conditions over time, all potential contamination sources will increase and accumulate; this is also a real restriction on life support technology choices

- **Screen, identify and catalog all Earth-based "signature" materials associated with EVA-system elements in order to recognize against potential "alien" life-bearing materials:**
  - Develop "Contamination Materials Reference Guideline"
    - Obstacle – Time and cost maybe excessively prohibitive; also, we may not fully capture all associated materials and constituents

- **To potentially mitigate "backward" PP contamination, quarantine, isolate or discard all EVA surface-exposed hardware items (other than scientific samples) at habitat base-site as a "non-return" to Earth policy:**
  - Provide "peel-off layer" over portions of suit to remove/discard prior to airlock entry
  - "Decontaminate" EVA hardware items prior to airlock entry
    - Obstacle – We need to assess logistics and costs associated with "throw-away" versus "re-use" philosophy

- **Definition of "design-to" requirements is critical to understanding costs**
  - We have a pretty good idea of what we vent, and how much…what we don't know is what is acceptable and what isn't…

Outstanding Planetary Protection Questions
Developed by D. Eppler

- Will interplanetary disposal during transit be allowed, and what conditions will be imposed?
- Will any waste be allowed to be stored or disposed of on/below the surface if adequately contained? If so, what level of containment would be sufficient? What would be the necessary characteristics of the waste? How long will containment need to be assured? What level of certainty is required (e.g., $<10^{-4}$)? Does the state of the waste need to be rendered so as to preclude serving as a substrate for biological growth (i.e., mineralized)? Will wastes be allowed to remain in the surface habitat after mission completion (or do they need to be contained on the surface or returned home)?
- Will there be constraints as to what will be allowed to be returned to Earth (i.e., potential for back-contamination)? The inside of the returning spacecraft (?) may be contaminated to some degree from EVA interchange. This material will enter the solid, liquid and gas streams through various means. Therefore, how do we return home?
- Determine how internal habitat ALS technologies might affect the potential for planetary surface contamination (e.g., increased bio-loads on suits and equipment, venting gases/liquids/particulates to planetary atmosphere via airlocks) Also – venting as a potential part of the ALS systems – e.g. CO_2 (and contaminants) from a regenerable CO_2 removal system like CDRA or swing bed, methane from a Sabatier system, “burp” gases from a carbon formation reactor etc. – not directly EVA contaminants, but certainly a factor to be considered in assessing what limits and controls are appropriate for EVA.

Outstanding Planetary Protection Questions

Developed by D. Eppler

- How "clean" do we need to be inside in order to support external PP requirements? Will ALS be involved with cleaning issues, or will someone else be tasked with that? Will ALS need to handle cleaning by-products?
- Are there special measures that should be taken to avoid the propagation of extraterrestrial organisms in ALS systems? For example, if waste is stored "as-is", the waste could serve as a growth medium (if contaminated). The same is true for biological processors for waste, water and air.
- What extent of gas venting (from habitats) will be allowed? What compounds will be allowed/excluded? Will particulate (microbial, organic, inorganic) control be necessary?
- Determine similar restrictions and requirements to be placed on human extravehicular activity (EVA) systems
- Determine restrictions and/or required procedures to be emplaced for human activities and systems for use outside the habitat, particularly with respect to:
  - Subsurface access
  - Use and/or distribution of fluids outside the habitat
  - Planned or unplanned biological experiments or releases
- Determine what types of monitoring systems, procedures and equipment are necessary to assist in PP policy implementation and verification of compliance. This includes issues regarding contamination of the planetary surface, habitat contamination and return of spacecraft and samples to Earth.